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# Ecology of Cobble Mulch Gardens : Structures for Modification of Soil Moisture Dynamics

Final Project Report

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## Ecology of Cobble Mulch Gardens:

## Structures for Modification of Soil Moisture Dynamics


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**Ecology of Cobble Mulch Gardens:**

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## Ecology of Cobble Mulch Gardens:

## Structures for Modification of Soil Moisture Dynamics

### INTRODUCTION

Water is the most important single environmental variable in arid and semi-arid ecosystems. It appears that prehistoric Native American agriculturalists successfully farmed large areas of arid and semi-arid lands in the Rio Chama, El Rito, and Ojo Caliente Valleys. Their farming techniques appeared to rely mostly or solely upon direct rainfall (dryland farming). The success of these dryland practices involved the use of gravel or cobbles applied like a mulch on the soil surface. Apparently, the primary function of the mulch was to reduce direct evaporation, which left more soil moisture available for crop growth. A detailed understanding of these techniques may allow revival of dryland farming practices in the water-limited Southwest.

Much of what we "know" about these dryland agricultural features (termed cobble mulch gardens throughout this report) is derived from interpreting the "record" preserved in and around the gardens. Prior to this study, our knowledge of cobble mulch gardens was based upon a limited number of excavated gardens. These gardens, excavated by the Museum of New Mexico, Laboratory of Anthropology, were in the highway right-of-way located along US 84 between Española and Abiquiu (Anschuetz et al. 1985) and along the right-of-way in the Ojo Caliente Valley along US 285. Both of these sites were close to the existing road and were heavily used by livestock in the area (Carl White, personal observation).

Based upon these experiences, it was proposed that cobble mulch gardens in this region had common physical characteristics. Certain physical features, which appeared to produce differential plant composition and higher cover within the garden plots, may be unique to the few gardens that were excavated rather than features common to all gardens. Also, some features may be the result of continued impact of grazing. Thus, gardens further from the road and with less use by livestock were sought to investigate whether these gardens had common physical features that have lead to the current chemical and biological composition of the plots. Such gardens were located north of the Ojo Caliente Hot Springs Resort with the aid of Paul Williams (Archeologist, Taos Resource Area, Bureau of Land Management).

### RESEARCH HYPOTHESES

Based upon the limited number of excavated gardens, certain physical features appeared in all gardens. Some of these features may represent characteristics that were selected by the Native Americans in establishment of the gardens, although the actual means of selection is unknown. These predictions of common features are presented in the form of hypotheses about the physical, chemical, and biological characteristics of the cobble mulch gardens. Rigorous statistical testing of these hypotheses was not intended through this study. Rather, this investigation was designed to determine if gardens representing a range of present conditions within the Ojo Caliente valley and lesser disturbed by livestock grazing contained characteristics consistent with these predictions. These hypotheses may be the basis of more intensive investigations in the future.

Hypothesis 1. Native Americans placed cobble mulch gardens on alluvial gravel terraces that had sandy upper soil horizons (sandy or sandy loam texture).

Hypothesis 2. The gardens were constructed by placing cobbles on top of or partially embedded into the upper soil horizon, creating compartments of different sizes, which were then covered with smaller cobbles and gravel.

Hypothesis 3. Native Americans selected sites for gardens that had subsurface soil horizons that interrupt the downward movement of soil moisture at a depth of about 20 to 40 cm (this horizon may be partially degraded by the presence of the garden).

Hypothesis 4. By producing a more favorable environment (greater soil moisture and stable soil surface), relative cover by native plants is greater on the cobble mulch gardens than in surrounding uncobbled areas. Also, plant species composition should resemble the undisturbed grassland with a greater number of disturbance species and individuals in the surrounding areas relative to the gardens.

Hypothesis 5. Soil fertility in the cobble mulch gardens is equal to or greater than outside areas. This hypothesis is partially based on the observation that the cobbles provide protection and retained characteristics of lesser disturbed sites within the general area.

Experimental support of the hypotheses were evaluated by sampling of plant composition and cover on the gardens versus outside gardens, and through sampling of the soil profile and soil analyses. Support for these hypotheses would be indicated by the sampled locations have the predicted characteristics.

## METHODS

### Site Selection

Sites (both gardens and outside areas) that exhibited the least amount of disturbance by livestock were desired for this research. As suggested by Paul Williams (BLM), gardens on BLM land approximately 1 to 1.5 km north of the Ojo Caliente Hot Springs Resort were selected (Figure 1). The gardens occur on Pleistocene fluvial gravel terraces (May 1979) that are west of the Rio Ojo Caliente. To keep the impact of this research to a minimum, only three gardens were sampled. The northern most site was on the upper terrace (Site 1), the middle site on the lower terrace above the Ojo Caliente River (Site 2), and the southern-most on the lower terrace at the base of a precambrian metarhyolite and gneissic granite (May 1979) hill that lies to the west of the terrace (Site 3).

### Vegetation Sampling

Ground cover and plant cover was determined using line-intercept transects (one transect per plot). Transects consisted of a meter tape with clear cm gradations. Each transect contained about equal distance within and outside of the gardens. The transect at Site 1 (labeled 1L) began about 4.5 m to the east of the garden, traversed the garden (which is about 9 m across), and ended about 4.5 m to the west of the plot (total length was 18 m). The transect at

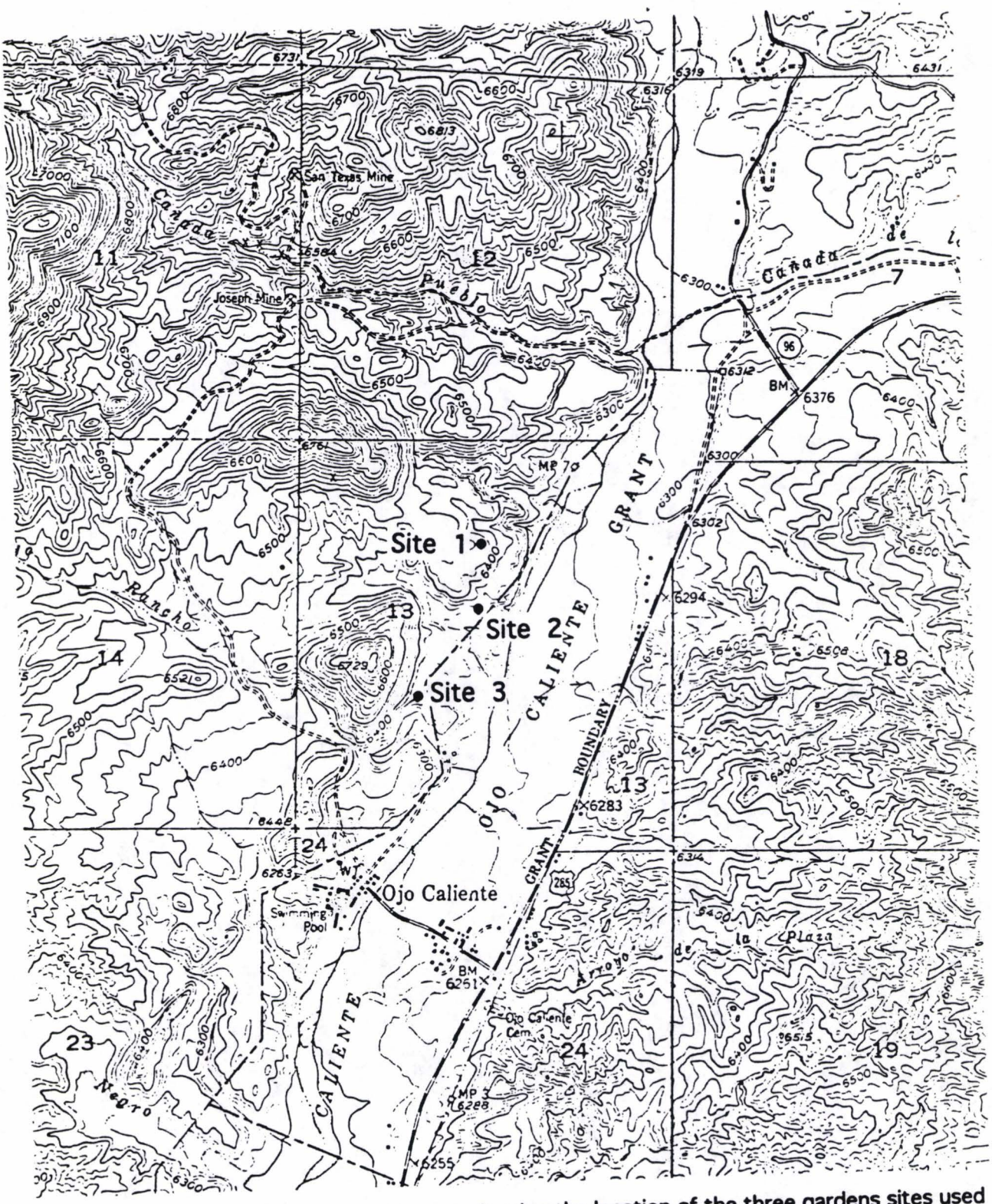
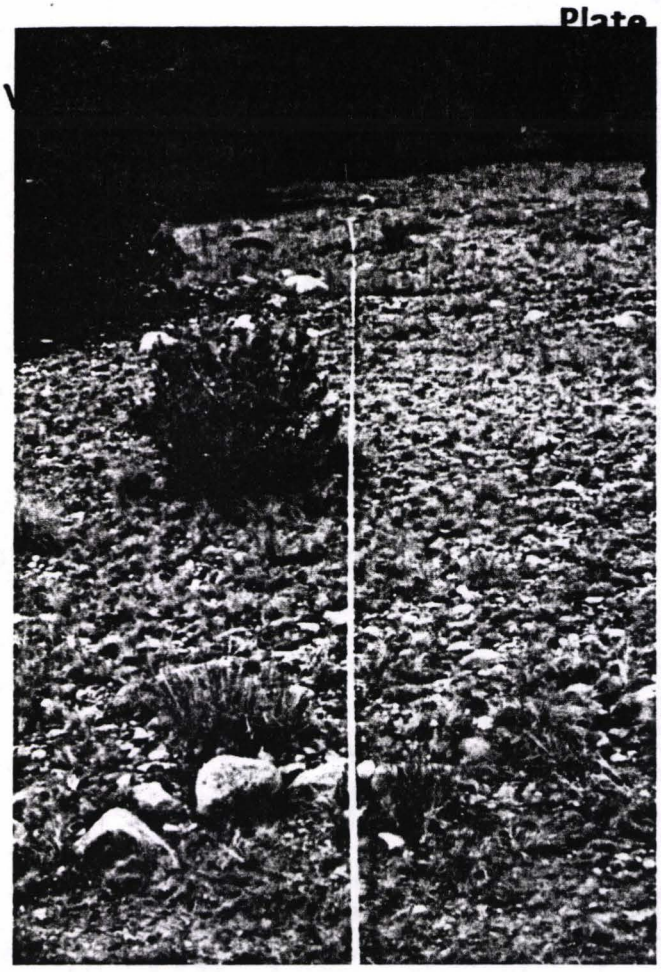
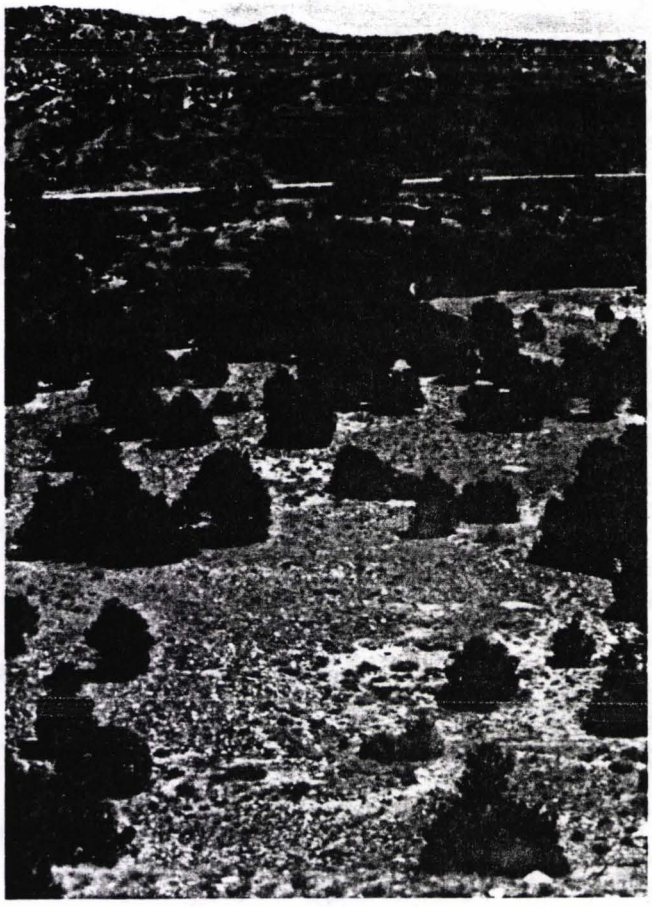



Figure 1. Portion of USGS topographic map showing the location of the three gardens sites used in this study.

Plate 1





View of Site 3 with 3L on right and 3S behind person on left (looking west).

Site 2 (labeled 2L), where the garden was a portion of a larger garden area that covered most of the terrace surface, was centered on the garden border with equal portions inside and outside the garden (total length was 18 m). The transect at Site 3 (labeled 3L) again was centered on the garden border with equal parts inside and outside the plot. The upper side of Site 3 appeared to be filled with eroded metarhyolite and gneissic granite from the upper slopes, so the line extended from the garden east onto the terrace material (total length was 11.8 m). Ground cover and plant cover were recorded as they intercepted the plane perpendicular to the ground as defined by the edge of the tape. Intercepts were recorded to 1.0 cm accuracy. Since some plants overshadow the soil surface some locations have both plant and ground cover, which can lead to total cover in excess of 100%.

### Soil Sampling and Analyses

To minimize impact of sampling, only one soil transect was sampled at each site. The ends of each transect were marked with an aluminum rod (1/4" by 3/4") stamped with the site number and "S" (1S at site 1, for example). At each transect, a total of six soil samples were collected using a 76 mm diameter tube (sample design pictured in Figure 2). Two samples of the 0-10 cm depth surface soil horizon (if present to that depth) were collected outside the plot (1 and 0.5 m from the garden border). The cobbles and gravel were removed from the surface inside the garden plot at approximately 0.5 and 1 m from the border. The soil from between the cobbles within an approximate 8 cm diameter area (about the size of the collection tube) were collected and combined with the 10 cm depth sample of the underlying A horizon. The surface of the B horizon was then exposed and samples of the top 10 cm of the B horizon were collected at approximately 0.5 and 1 m from the border.

All samples were placed on ice and transported to the laboratory for analyses. The samples were sieved and the portion that passed the 2 mm sieve was retained for analyses. Field water content was determined by loss upon drying at 105 C for 24 hrs. Organic matter was determined on the oven-dried sample by loss upon ignition at 500 C. Water holding capacity (WHC) was determined by first saturating a portion of each sample contained in a funnel with water, then allowing the sample to drain by gravity for 30 minutes. The amount of water retained by the sample was determined gravimetrically by drying the drained sample at 105 C for 24 hr.

Soil fertility was assessed by measurement of potentially mineralizable nitrogen (White and McDonald 1988). This method measures the amount of inorganic nitrogen (in the forms of ammonium and nitrate) extracted from the soil. Asymptotic production of inorganic nitrogen is reported as 'mineralizable nitrogen,' which is directly proportional to soil fertility. Asymptotic production was determined by extracting the inorganic nitrogen from subsamples adjusted to optimal water content (50% of measured WHC) and incubated at 20 C. Each subsample was incubated in a separate cup and contained 10 g dry-weight (DW) soil. One subsample of each treatment was immediately extracted with 100 ml 2 N KCl. After 18-24 hr., the clarified KCl was filtered through a Kimwipe® and analyzed for nitrate and ammonium on a Technicon AutoAnalyzer, providing the initial (or time 0) nutrient content. The remainder of the cups were covered with plastic wrap, sealed with a rubber band, and incubated in the dark at 20 C. The plastic wrap minimized water loss during incubation, yet exchange of $CO_2$ and $O_2$ was sufficient to keep the subsamples aerobic during incubation. Moisture content was

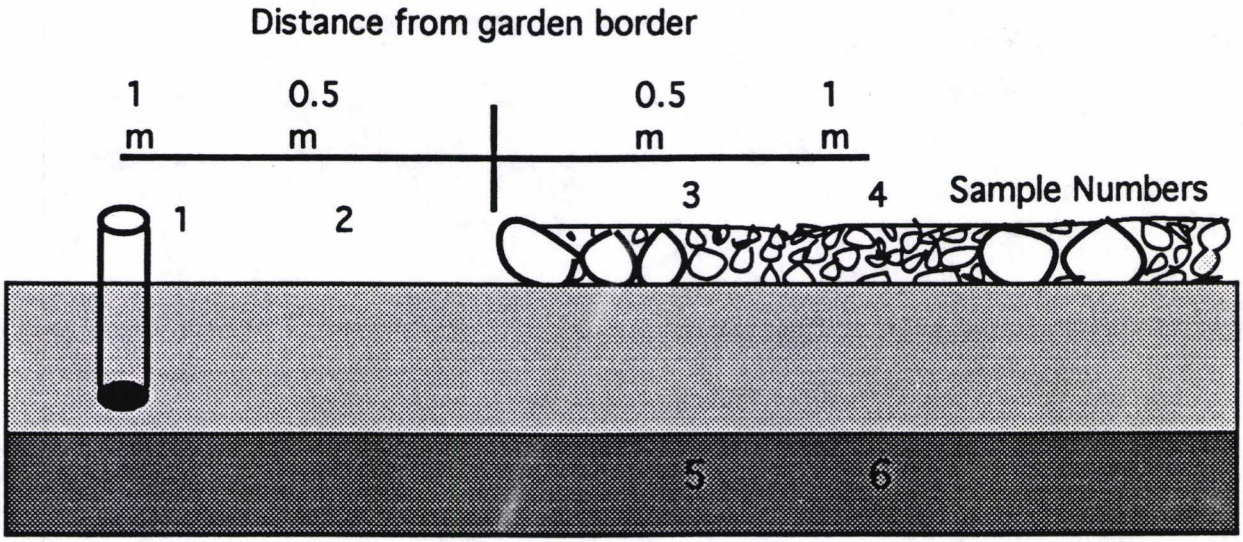



Figure 2. Schematic showing the approximate location and numbering of soil samples for assessment of fertility.

monitored by mass loss and replenished as needed. At various time intervals, a subsample of each treatment was removed and extraction with KCl by the same procedure used for the initial nutrient content analyses. The last extraction occurred after 70 days of incubation with mineralizable nitrogen reported as the asymptotic value during the incubation.

### Soil Profile Description

Following collection of the soil samples from 0.5 and 1 m from the border inside and outside the garden, a trench was dug to expose the soil profile. The trench at each site was dug to a depth that fine roots were nearly absent, which indicated the maximum depth at which nutrients are absorbed by plants. A characteristic portion of the profile outside the plot and inside the plot were described and each horizon was sampled for determination of soil characteristics. Particle-size (percent sand, silt, and clay) was determined by the hydrometer method (Day 1965). Soil organic matter by loss upon ignition. Following Kjeldahl digestion with $K_2SO_4$, $CuSO_4$, and concentrated sulfuric acid (Schuman et al. 1973), total nitrogen was determined by an alkaline phenol method (Technicon Industrial Method 98-70W) and total phosphorus by an ascorbic acid method (Technicon Industrial Method 94-70W).

### Soil Temperature

In July of 1994, four temperature probes were installed at Site 1 (upper-most terrace) at 2 and 20 cm depth both inside and outside the plot. All probes were connected to a Campbell data logger. The data logger was check at each site visit; however, a probe was chewed and removed by an animal prior the early September site visit, which caused a short or grounding of the circuit and all data prior to September 10 were lost. Only three soil probes were operational after that date.

On September 10, 1994, temperature probes and data loggers (HOBO™, Onset Instruments, Pocasset, MA) were installed at Site 1 and Site 2, at the base of the terrace north of the Round Barn, and approximately 100 m east of the Rio Ojo Caliente (one at each location). The data loggers were set to collect data for 30 days, taking one reading every 24 min. The data loggers were removed on Oct. 8, 1994, at which time it was noticed that the probe at Site 1 had been cut (which occurred on Sept. 24, 1994, according to the data).

### Precipitation

A tipping bucket precipitation gauge was installed at Site 1 and connected to the Campbell data logger. Prior to the September collection, all data from the tipping bucket also was lost, so data were only available from September 10 through October 8, 1994.

## RESULTS

The three excavated gardens in this study, which represent a range of garden conditions and locations within this local area, are all located on the Pleistocene fluvial cobble terraces. These landscape features are readily recognized on a geologic map (Figure 3, from May 1979). The cobble gardens along the highway right-of-way excavated by the Museum of New Mexico also occupied this geologic formations.

All gardens had sandy or loamy sand upper soil horizons (Figure 4, Table 1). These sandy surface horizons have low water holding capacity, which also indicates that infiltration rates should be high in these soils. The lower horizons at all gardens had higher clay content than the surface horizon (increase in clay content significant at $P<0.05$, Figure 4 and Table 1) and higher water holding capacity. The increase in clay content would tend to reduce infiltration below this horizon and act to retain water within the top 20 to 40 cm soil depth, which represents the rooting zone. There was no consistent pattern in soil organic matter distribution within the soil profiles; organic matter increased with depth in some profiles and decreased with depth in others (Figure 4). Also, the gardens did not have a consistent effect on soil organic matter. The total nutrient content (both total nitrogen and phosphorus) of the gardens is not significantly different from the profile outside the garden (Figure 5). However, mineralizable nitrogen (a measure of soil fertility) was highest in the A horizon inside the gardens, lower (although not significant) in the A horizon outside the gardens, and significantly lower in the B horizon within the plot (Table 1). This indicates that the B horizon has limited function with respect to nutrients. The presence of common fine and medium roots (Appendix A), which are capable of absorbing water but have limited nutrient uptake (which occurs primarily in very fine roots), in the upper portion of the B horizon also indicates its function as water retention and storage.

The distribution of ground and plant cover inside and outside the gardens (shown in Figure 6) shows some fairly clear patterns. Percent cover for the different cover types is very similar inside the gardens at all sites, whereas percent cover by type shows much greater variation across sites outside the gardens. The greater concentration of rocks (including gravel and cobble) inside the gardens is evident at all sites. There was an interesting pattern in cryptogam cover outside the gardens across the sites. Although erosion was evident at all sites, it was most severe at site 3 where nearly all the A horizon was removed beyond about 1 m from the garden border. The exposed B horizon, that has higher clay content, supported a dense cryptogam cover. In contrast, site 1 retained the sandy A horizon. The near absence of cryptogam cover at site 1 and high cover at site 3 suggests better establishment and/or survival of cryptogams on soils with higher clay content.

The plant cover was more consistent across sites inside than outside the gardens. In addition, plant species composition was more consistent across sites inside than outside the gardens (Table 2). The gardens were dominated by the native grama grasses with disturbance species increasing in cover and frequency outside the gardens.

Although there were limited temperature data due to destruction of equipment by animals, some interesting patterns were shown. Diurnal temperature fluctuation at the same depth was greater within than outside the garden (Figure 7). This pattern indicates that the gardens differ from outside the gardens in some other physical property. Which factors contribute to that difference may be determined by future investigations.

Diurnal fluctuation in air temperature was greatest at the valley sites and the lowest at the garden sites on the terraces (Table 3). Also, mean temperature was colder at the valley sites than on the terraces ($P<0.05$). The absolute minimum temperature during the measurement period was at or below freezing at the valley sites while the terrace was nearly a full degree centigrade higher (Table 4).

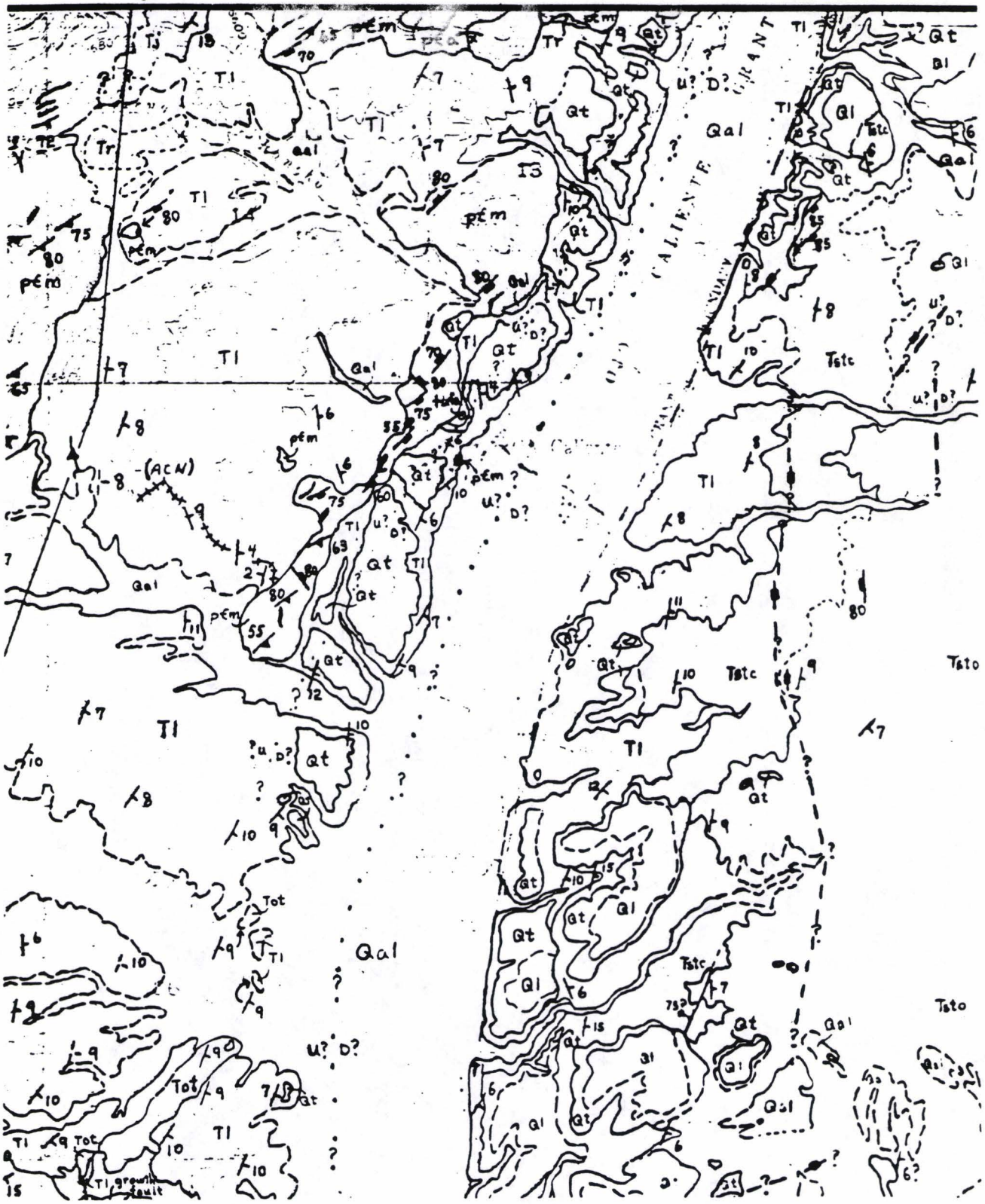



Figure 3. Portion of geologic map (May 1979) indicating the formations on which the gardens are located (indicated by Qt).

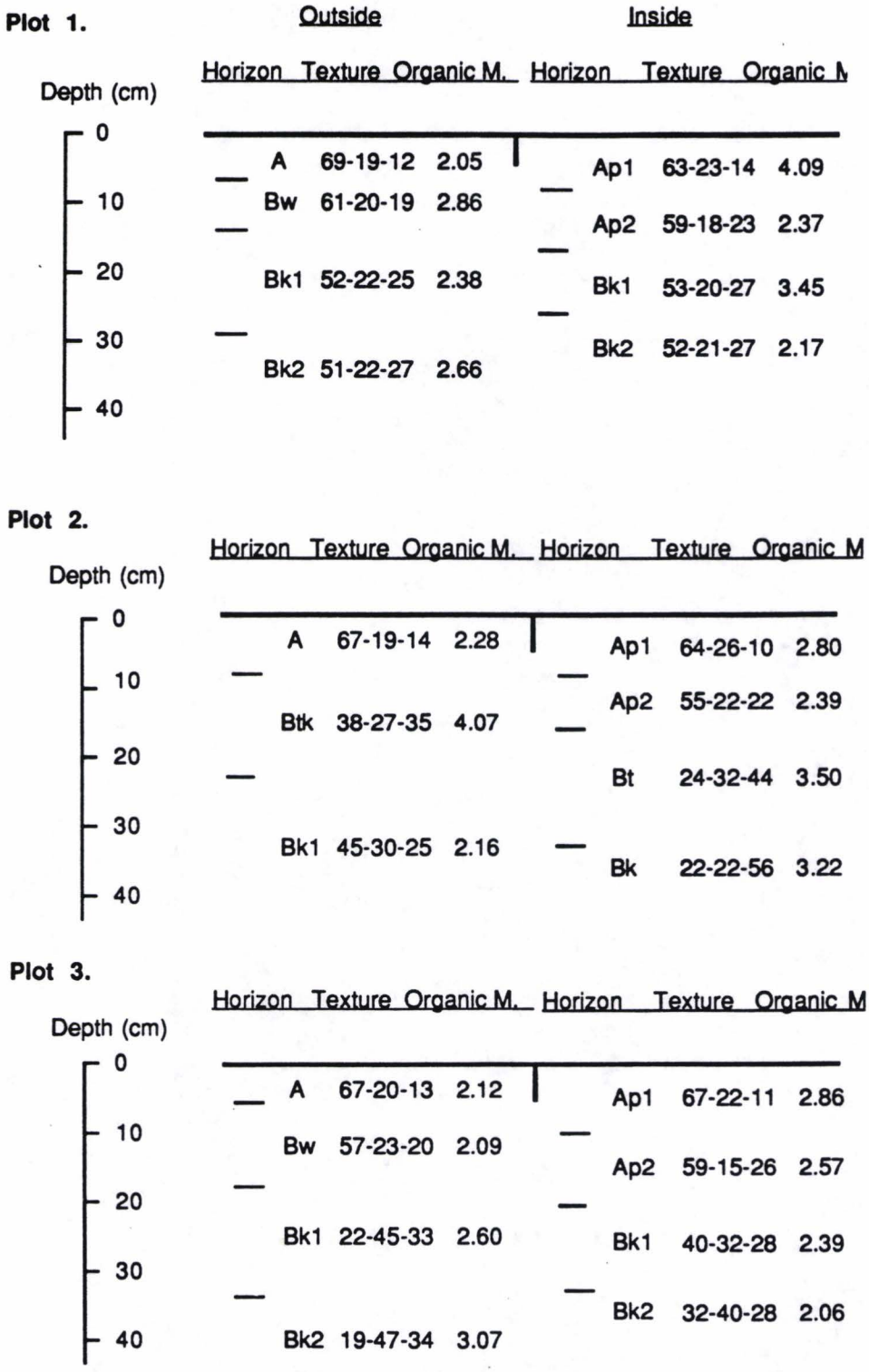



Figure 4. Soil profile characterizations indicating horizons and depths, texture (sand-silt-clay percent) and organic matter percent for each horizon.

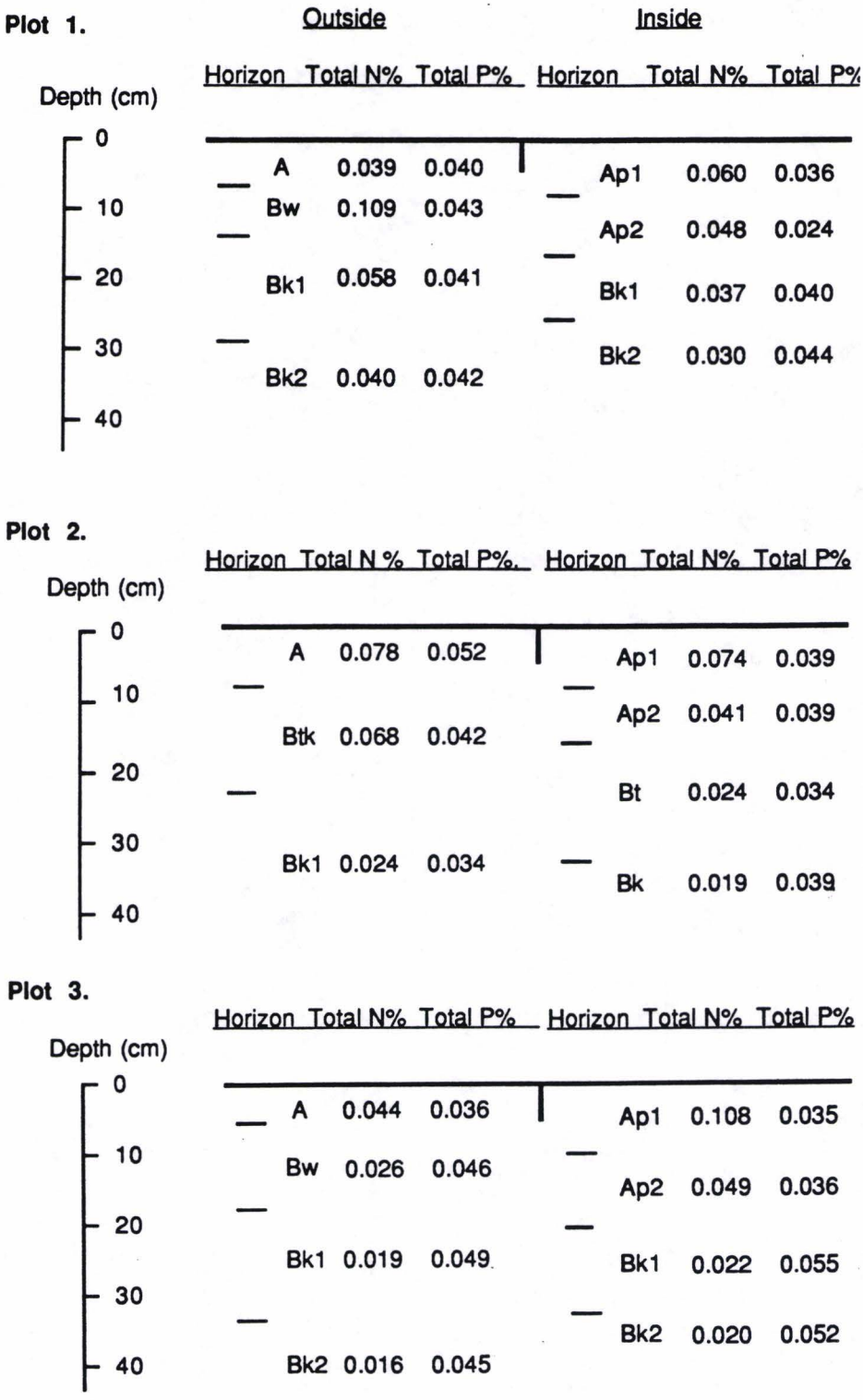



Figure 5. Soil profile characterizations indicating horizons and depths, total nitrogen and total phosphorus percent for each horizon.

Table 1. Summary comparison for characteristics of areas inside gardens, outside gardens, and for the B horizon inside gardens. Characteristics are the mean of the indicated positions at all three sites.

| Characteristic | Position | | |
|---|---|---|---|
| | Outside (1,2) | Inside (3,4) | B Horizon (5,6) |
| % Sand | 57 a* | 65 a | 55 a |
| % Silt | 21 ab | 24 a | 18 b |
| % Clay | 22 ab | 11 b | 27 a |
| % Organic Matter | 2.25 a | 2.09 a | 2.22 a |
| Water Holding Capacity (ml water/g soil) | 0.48 ab | 0.38 b | 0.54 a |
| Field Water Content (ml water/g soil) | 0.02 b | 0.082 a | 0.085 a |
| Nitrogen Mineralization (ug N/g soil/day) | 0.15 ab | 0.28 a | 0.04 b |

* Within a row, values without the same letter are significantly different ($P<0.05$)

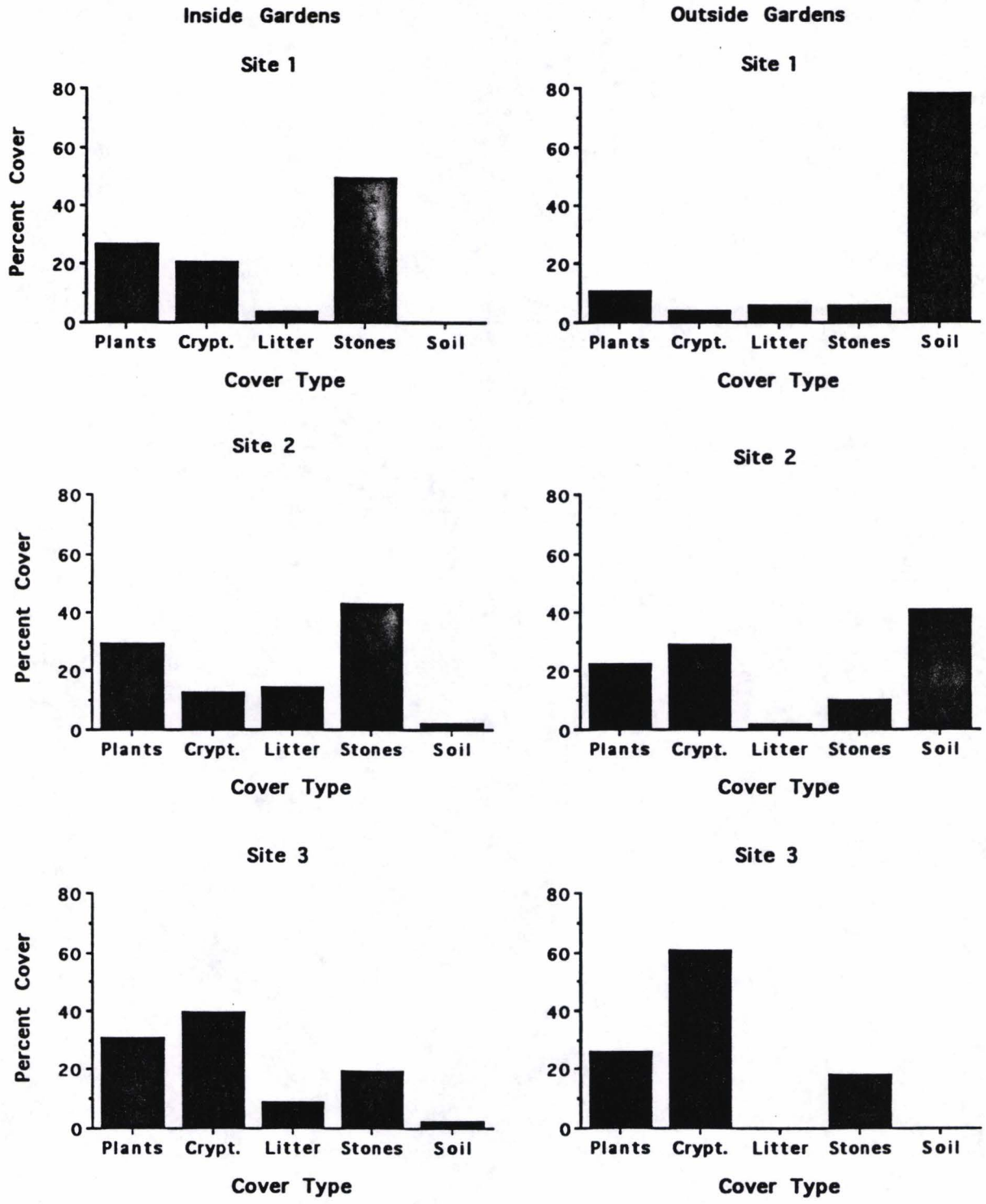



Figure 6. Percent cover for plants, cryptogamic crusts (Crypt.), litter, stones, and bare soil (soil) for transect portions inside and outside the gardens at all sites.

Table 2. Plant species and percent cover inside and outside the garden plots at each site.

| | | Site 1 | | Site 2 | | Site 3 | |
|---|---|---|---|---|---|---|---|
| Species Name | Common Name | Inside | Outside | Inside | Outside | Inside | Outside |
| *Bouteloua gracilis* | Blue Grama | 15.8 | 1.8 | 24.1 | | 18.4 | 1.8 |
| *Bouteloua curtipendulum* | Side-oats Grama | 8.2 | 1 | | | | |
| *Aristida longiseta* | Red Three-awn | 1.7 | | | | | |
| *Hilaria jamesii* | Galleta | 1 | 3.6 | 3.2 | 13.9 | 4.6 | |
| *Juniperous monosperma* | One-seed Juniper | | | 0.2 | | | |
| *Gutierrezia sarothrae* | Snakeweed | | 4.1 | 1.9 | 4.4 | | 3.6 |
| *Sporobolus airiodes* | Alkali Sacaton | | | | 3.3 | 2.5 | 18.6 |
| *Sporobolus cryptandus* | Sand Dropseed | | | | | 2 | |
| Sporobolus sp. | dropseed | | | | | 1 | |
| *Opuntia polyacantha* | Starvation Cactus | | | | 0.7 | 2.4 | |
| *Leucelene ericoides* | | | | | | | 0.9 |

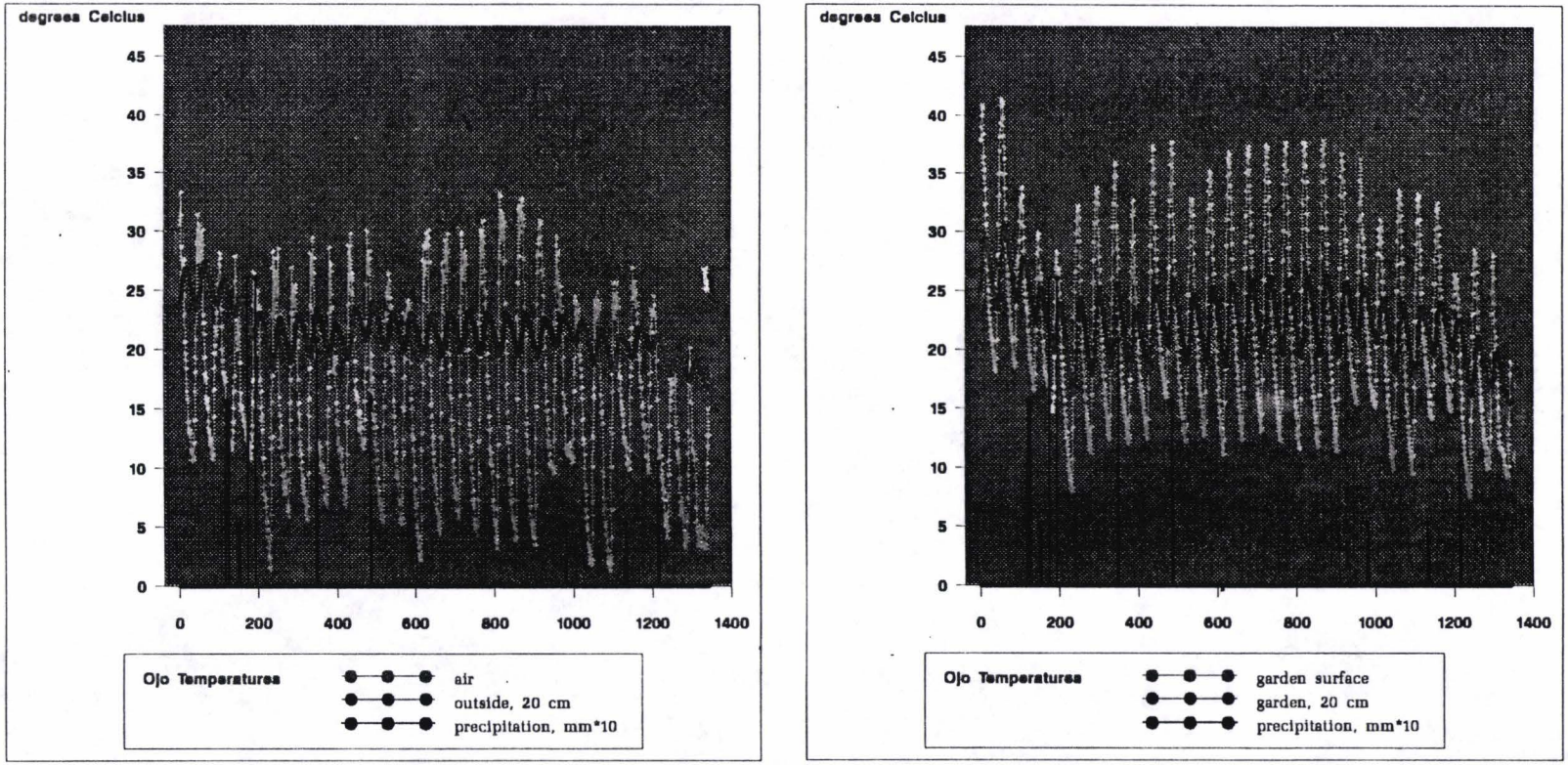



Figure 7. Temperature of soil (outside the plot at 20 cm depth) and air, and precipitation at Site 1 from Sept. 10 to Oct. 8, 1994 (left); and soil temperature at 2 cm (surface) and 20 cm depth inside garden at Site 1, and amount of precipitation for the same time period (right).

Table 3. Summary of air temperature data for sites near Ojo Caliente. Data collected from Sept. 10, 1994, to Sept. 24, 1994. Temperature expressed as centigrade.

| Site | Max. | Min. | Mean* | Std. Error | n |
|---|---|---|---|---|---|
| Garden #1 | 34.5 | 0.94 | 16.2 b | 0.254 | 811 |
| Garden #2 | 33.9 | 1.7 | 16.5 a | 0.263 | 811 |
| Valley near Barn | 35.5 | 0.43 | 15.5 c | 0.273 | 811 |
| Valley east of River | 31.6 | 1.96 | 15.7 c | 0.263 | 811 |

* Means followed by different letters are significantly different ($P<0.05$).

Table 4. Summary of air temperature data for sites near Ojo Caliente. Data collected from Sept. 10, 1994, to Oct. 8, 1994. Temperature expressed as centigrade.

| Site | Max. | Min. | Mean* | Std. Error | n |
|---|---|---|---|---|---|
| Garden #2 | 34.4 | 1.2 | 15.96 a | 0.198 | 1670 |
| Valley near Barn | 37.1 | -0.81 | 14.88 c | 0.205 | 1670 |
| Valley east of River | 33.5 | 0.18 | 15.02 b | 0.198 | 1670 |

* Means followed by different letters are significantly different ($P<0.05$).

## DISCUSSION

Nearly all of the hypotheses are supported by the results of this study. Because the results were predicted rather than formulated from the results, we fell this adds greater strength to this investigation. Furthermore, most of the predicted patterns occurred across the intentionally chosen wide range of garden sites (differences across sites are reflected in the outside garden cover between sites).

> Hypothesis 1. Native Americans placed cobble mulch gardens on alluvial gravel terraces that had sandy upper soil horizons (sandy or sandy loam texture).

This study showed that all of the gardens investigated to date are located on the Pleistocene fluvial cobble terraces, landscape features that are readily recognized on the geologic map of May (1979, Figure 1). Also, all gardens have sandy A horizons. This feature is important because (1) it would allow rapid infiltration of water and (2) a larger proportion of soil water can be extracted from sandy soils than from soils with greater clay content. Thus, rain could rapidly infiltrate and a high proportion is available to plants. This contrasts from the present situation where spaces between rocks on the surface are now filled with eolian particles and plants, predominantly native grama grasses, which may restrict rates of infiltration.

> Hypothesis 2. The gardens were constructed by placing cobbles on top of or partially embedded into the upper soil horizon, creating compartments of different sizes, which were then covered with smaller cobbles and gravel.

This study did not directly address this hypothesis. However, this study did generate results that may support this hypothesis. All gardens had higher rock cover than outside the gardens (Figure 6). This may indicate that rocks were removed from outside the gardens and concentrated within the gardens. In addition to their effects as mulch, rocks increase the rate of water infiltration and reduce the rate of erosion when set on the soil surface (Possen et al. 1990). For example, Kemper et al. 1994 determined that gravel mulches 5 cm thick resulted in accumulation of 80 to 85% of the annual precipitation at their research site near Ft. Collins, CO. This may account for (1) high cover by native grasses on the gardens and (2) the stability of the gardens from subsequent erosion and trampling. Also, there was no abrupt change in soil horizons at the edge of the gardens. This suggests that the gardens did not occupy "unique" sites with the greater area, but were concentrated within an area with generally uniform soil characteristics.

Over time, the function of the gravel surface would change. With working during gardening, the cobbles would tend to stay on the soil surface with wind-blown particles falling to the soil surface. Also, unwanted plants were probably removed, leaving the spaces between the gravel open. After abandonment, the cobbles would have favored eolian deposition (Gossens 1994) and the spaces between the gravel and cobble are now filled with eolian material and plants, predominantly native grasses and cryptogamic crusts. This surface now has gravel and cobble imbedded in the surface, which changes its hydrologic properties (Possen et al. 1990) and probably lowers rates of infiltration.

> Hypothesis 3. Native Americans selected sites for gardens that had subsurface soil

horizons that interrupt the downward movement of soil moisture at a depth of about 20 to 40 cm (this horizon may be partially degraded by the presence of the garden).

All sites have argillic B horizons extending across the garden borders. This indicates that these are nearly terrace-wide features and not pockets of unique soils. These argillic horizons function to retain water within the upper soil horizons. Similar functions could be achieved by the presence of a caliche horizon without a substantial change in texture.

Sandor et al. (1990) also reported that areas used by Native Americans for agriculture in the Mimbres region of souther New Mexico had argillic subsurface horizons. Apparently, argillic horizons or features with similar function were often used for semiarid agricultural practices to intercept the downward movement of water and retain moisture in the rooting zone.

Hypothesis 4. By producing a more favorable environment (greater soil moisture and stable soil surface), relative cover by native plants is greater on the cobble mulch gardens than in surrounding uncobbled areas. Also, plant species composition should resemble the undisturbed grassland with a greater number of disturbance species and individuals in the surrounding areas relative to the gardens.

Both predictions within this hypothesis are supported by the results. Within the gardens, native grass species were the major species (Table 2). Outside the gardens, the native grasses had less cover and disturbance species the highest cover. Also, the gardens have a high and relatively consistent coverage by cryptogamic crusts. The presence of the crusts may be important from at least two perspectives. First, a student research project on the Sevilleta demonstrated that soil moisture was significantly higher beneath crusts, apparently due to reduced evaporation from crust surfaces (Karyn Coleman, Research Experience for Undergraduates, Sevilleta Long-Term Research Project, Summer of 1993). Second, the crusts appear to contribute significant amounts of nitrogen to the soil (Loftin and White, In Press). Nitrogen is the nutrient element most often limiting plant production. Replenishment of this essential nutrient is an important aspect that would determine long-term sustainable use of these plots for historic agricultural production.

These results suggest that these structures may be suited for revegetation of disturbed areas by native grasses, an effort that has met with mixed results. These features may require no maintenance and afford protection of native grasses for revegetation-reclamation efforts within this region.

Hypothesis 5. Soil fertility in the cobble mulch gardens is equal to or greater than outside areas. This hypothesis is partially based on the observation that the cobbles provide protection and retained characteristics of lesser disturbed sites within the general area.

Soil fertility of the gardens was either not different from areas outside the garden or slightly higher. Both total nitrogen and phosphorus were not different when averaged over the total profile within or outside the gardens. However, mineralizable nitrogen was highest in the upper horizon within the gardens, lowest in the argillic horizons within the gardens, and intermediate outside of the gardens. This contrasts with the results of Sandor et al. (1990) in southern New Mexico, where agricultural practices initiated soil instability that has lead to

lower total N and P in sites used for agriculture. The main differences in agricultural practices is the use of gravel and cobble in the cobble mulch gardens of Northern New Mexico. The rock on the soil surface has lead to protection from erosion and resistance to trampling impact of grazing. Thus, the effects of Native American agricultural practices on soil fertility and nutrients vary dependent upon the type of practice.

Effects of past cultivation on soil chemical and physical properties vary substantially dependent upon the site characteristics and climate. Kalisz (1986) studied the effects of old fields (used from 1800-1930) that were located on steep Appalachian slopes on soil properties. He found only minor differences in the properties of cultivated versus uncultivated soils; however, the lack of differences were attributed to the location of old fields on sites characterized by favorable water regimes, and by deep, porous soils with uniform physical properties throughout the rooting depth. Surface soils of these landscape positions are resistant to permanent erosional degradation, and are rapidly rejuvenated by processes associated with reforestation (the vegetative communities of the region). In contrast, agricultural practices that lead to soil instability in the semiarid Southwest will promote erosion and loss of nutrients.

## SUMMARY

It is hypothesized that the current appearance of the plots is largely the result of the presence of common physical soil features and the modification of the surface by Native Americans. It appeared that Native Americans placed cobble mulch gardens on terraces with sandy or loamy sand surface horizons. The sandy horizon ranges in depth from about 20 cm to a maximum of 50 cm. The subsurface horizon (B horizon) has a finer texture (higher clay content) that acts to interrupt the downward movement of soil moisture. Such horizons may include either (1) a bed of finer textured alluvium, (2) unsorted sands, gravel and cobbles, (3) an argillic horizon, or (4) a caliche horizon. Native Americans covered the surface sand horizon with a mixture of gravel and cobbles and aligned larger cobbles to form "cells" or compartments within the larger garden. Native Americans concentrated locally occurring surface cobbles into the smaller garden areas or obtained cobbles and gravel from nearby "borrow pits" to place within the gardens. The greater concentration of cobbles within the gardens lends a patch-work quilt appearance to these areas with patches of gardens within a matrix of surrounding sandy areas. This patchy appearance is enhanced by visual differences in vegetation, with gardens noticeably higher in plant cover than the surrounding area, which is often a "barren" matrix.

The primary functions of these gardens appear to be the reduction of direct evaporative loss of soil moisture and stabilization of the soil surface. The cobbles perform two functions. First, they act to reduce erosion by favoring rapid infiltration. Second, they act as a mulch to reduce evaporation. The cobbles may also reduce loss of soil moisture by creating a temperature gradient along which water vapor moves from hotter soils between the cobbles and condenses on the cooler surfaces on the bottom of the cobbles. This net movement of water to areas below the cobbles increases soil moisture, which attracts roots to that area. The roots in turn help initiate the carbonate coatings found along the bottom of the cobbles throughout that area. The sandy soils allow plants to remove a greater percentage of soil moisture relative to finer textured clay soils. Thus, the gardens rapidly absorb precipitation, reduce the rate of loss from the soil surface, and afford a higher proportion of soil moisture to crop plants.

Cobble mulch gardens presently support greater plant and cryptogamic crust cover than surrounding areas, which is particularly evident in areas with grazing. The cobble mulch acts to stabilize the soil surface and protect crusts and roots from damage by grazing animals. As a result, cobble mulch gardens presently function as islands of refugia for local vegetation (and perhaps associated fauna). These islands of refugia may act as source of seeds and genetic material to enhance the present rate of recovery of disturbed grasslands.

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## Environmental Impact

Environmental impact from this work was kept to a minimum. The area selected was recommended by Paul Williams of the BLM. Soil samples were collected from only one side of three garden areas. The soil trenches were about 3 m long, 1.5 m inside and outside the plot. The ends of the soil trenches were marked with 1/4" by 3/4" aluminum rod stamped with the site number followed by "S". Each plant transect was marked with identical bar stamped with the site number followed by "L". After all sampling, the trenches were backfilled. With the exception of the transect and soil profile markers, all materials have been removed from the site.

## Appendix A

## Soil Descriptions:

### Site 1--Inside Garden

Ap1--1-8 cm: color 7.5 YR 3/4 moist, 7.5 YR 5/4 dry; extremely gravelly sandy loam; single grain loose with pockets of weak fine subangular blocky structure; loose to hard dry consistence; loose to friable moist consistence; slightly sticky wet consistence; 50% gravel, 20% stones; many very fine and fine, common medium roots; noneffervescent; abrupt smooth boundary. *Ap1 has single grain loose structure with "pockets" of fine medium subangular blocky peds; abrupt color change between the Ap and Bk horizons.

Ap2--8-17 cm: color 7.5 YR 4/4 moist, 7.5 YR 5/4 dry; sandy loam; massive parting to loose fine subangular block structure; slightly hard parting to hard dry, friable moist, slightly sticky wet consistence; 15 % gravel, 5 % stones; common very fine and fine, few medium roots; noneffervescent parting to slightly effervescent; abrupt wavy boundary.

Bk1--17-25 cm: color 10 YR 4/6 moist, 10 YR 5/4 dry; clay loam; weak parting to moderate subangular blocky structure; slightly hard dry, friable moist, sticky wet consistence; 10% gravel; common very fine, fine and medium roots; strongly effervescent; clear wavy boundary.

Bk2--25-40+ cm: color 10 YR 4/6 moist, 10 YR 6/4 dry; clay loam; weak parting to moderate subangular blocky structure; very rigid dry, friable moist, sticky wet consistence; 10% gravel; common medium, few coarse roots; violently effervescent.

### Site 1--Outside Garden

A--0-7 cm: color 10 YR 3/6 moist, 10 YR 5/4 dry; gravelly sand loam; loose single grain structure; slightly sticky wet consistence; 20% gravel; few very fine, fine and medium roots; slightly effervescent; abrupt wavy boundary.

Bw--7-14 cm: color 10 YR 3/6 moist, 10 YR 4/6 dry; loam; slightly hard dry, friable moist, slightly sticky wet consistence; 15% gravel; common very fine and fine, few medium roots; strongly effervescent; clear wavy boundary.

Bk1--14-29 cm: color 10 YR 4/6 moist; 10 YR 6/4 dry; clay loam; moderate medium subangular blocky structure; rigid dry, friable moist, sticky wet consistence; 10% gravel; common very fine and fine, few medium roots; violently effervescent; clear wavy boundary.

Bk2--29-40+ cm: color 10 YR 4/6 moist; 10 YR 6/4 dry; clay loam; moderate medium subangular blocky structure; rigid dry, friable moist sticky wet consistence; 10% gravel; few very fine and fine roots; violently effervescent.

NOTES: A horizon appears eroded (truncated) and wind-reworked.

## Site 2--Inside Garden

Ap1-- 0-9 cm: color 7.5 YR 4/4 moist, 7.5 YR 5/4 dry; extremely gravelly sandy loam; slightly sticky wet consistence; 50% gravel, 10% cobble; common very fine and fine, few medium roots; noneffervescent, abrupt smooth boundary.

Ap2--9-16 cm: color 7.5 YR 4/4 moist, 7.5 YR 5/4 dry; loam; medium parting to moderate medium angular blocky structure; very hard dry, friable moist, sticky wet consistence; 20% gravel; common very fine and fine, few medium roots; noneffervescent; abrupt smooth boundary.

Bt--16-34 cm: color 10 YR 4/5 moist, 10 YR 5/6 dry; silty clay loam to clay loam; moderate medium prismatic; hard dry, firm moist, sticky wet consistence; 5% gravel, 1% cobble; common very fine and fine, few medium roots; slightly to strongly effervescent; clear wavy boundary.

Bk--34-50+ cm: color 10 YR 5/4 moist, 10 YR 6/4 dry; silty loam to clay loam; friable moist, sticky wet consistence; 5% gravel, 1% cobble; few very fine, fine and medium roots; slightly to strongly effervescent.

## Site 2--Outside Garden

A--0-8 cm: color 10 YR 4/4 moist, 10 YR 5/4 dry; sandy loam to loam sand; loose dry, ? MOIST, nonsticky wet consistence; 15% gravel, 5 % stones; common very fine and fine roots; non effervescent; abrupt smooth boundary.

Btk-- 8-23 cm: color 10 YR 4/6 moist, 10 YR 5/6 dry; silty clay loam to clay loam; moderate medium prismatic; hard dry, firm moist, sticky wet consistence; 10% gravel; common very fine and fine, few medium roots; strongly effervescent; clear wavy boundary.

Bk1-- 23-40+ cm: color 10 YR 4/6 moist, 10 YR 5/6 dry; silty clay loam to clay loam; hard dry, firm moist, sticky wet consistence; 5 % gravel, 1% cobble; few very fine and fine, few medium roots; strongly effervescent.

## Site 3--Inside Garden

Ap1-- 1-10 cm: color 7.5 YR 4/4 moist, 7.5 YR 5/4 dry; gravelly sandy loam; loose single grain; nonsticky wet; 40% gravel, 20% stone; many very fine and fine roots; non effervescent; abrupt smooth boundary.

Ap2-- 10-20 cm: color 7.5 YR 4/4 moist, 7.5 YR 6/4 dry; clay loam; medium parting to weak medium subangular blocky; hard dry, very firm moist, sticky wet consistence; 15% gravel; common very fine and fine roots; strongly effervescent; abrupt smooth boundary.

Bk1-- 20-32 cm: color 7.5 YR 4/4 moist, 7.5 YR 5/4 dry; silty clay loam; weak fine prismatic parting to moderate medium subangular blocky; hard dry, friable moist, sticky wet; 10% gravel; few very fine and fine roots; violently to strongly effervescent; clear wavy boundary.

Bk2-- 32-50+ cm: color 7.5 YR 4/4 moist, 7.5 YR 5/4 dry; silty clay loam; moderate medium subangular blocky; slightly hard dry, friable moist, sticky wet; <5% gravel; few very fine and fine roots; violently effervescent.

## Site 3--Outside Garden

A-- 0-6 cm: color 7.5 YR 4/4 moist, 7.5 YR 5/4 dry; gravelly sandy loam; loose single grain; slightly sticky wet; 20% gravel, 10% cobble; few very fine and fine roots; strongly effervescent; abrupt wavy boundary.

Bw-- 6-18 cm: color 7.5 YR 5/4 moist, 7.5 YR 6/4 dry; silty clay loam; weak medium prismatic parting to moderate medium subangular blocky; hard dry, firm moist, sticky wet; 15% gravel; common very fine and fine roots; strongly to violently effervescent; clear wavy boundary.

Bk1-- 18-34 cm: color 7.5 YR 5/4 moist, 7.5 YR 6/4 dry; silty clay loam to clay loam; weak medium prismatic parting to moderate medium subangular blocky; very hard dry, firm moist, sticky wet; <5% gravel; common very fine, few fine roots; violently effervescent; clear wavy boundary.

Bk2-- 34+cm: color 7.5 YR 4/4 moist, 7.5 YR 5/4 dry; silty clay loam; moderate medium subangular blocky; friable moist, very sticky wet; <5% gravel; few very fine and fine roots; violently effervescent.

NOTE: Bw has pockets of coarse grain granitic derived cobbles, gravels, and detrital material, making the texture sandy loam parting to silty clay loam.